

London Science Museum Launch Pad Extension Project
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Abstract

The project team developed exhibit extensions for the London Science Museum's outreach program associated with the hands-on gallery, Launch Pad. The team researched effective extensions, met with Science Museum staff, designed prototypes, and evaluated these prototypes with museum staff, schoolteachers, and students. Based on the evaluations, the team adjusted the prototypes to complete exhibit extensions that complemented classroom lesson plans while allowing teachers to demonstrate scientific principles with confidence and increasing students' interest and knowledge in science.

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Executive Summary

The London Science Museum is in the process of expanding its hands-on children's gallery, Launch Pad. In an effort to raise the knowledge and interest level of students about science, the museum requested that the team develop hands-on activities that demonstrate some of the principles taught through exhibits in the Launch Pad gallery. The team also developed these exhibit extensions to support teachers by supplementing their lesson plans.

In order to understand the scope of the project, the team researched the goals of museums, outreach programs, hands-on and interactive exhibits, and the effectiveness of each. Museums aim to increase the ability of their exhibits to attract visitors and aid in the learning process. Based on an extensive review of literature on informal education, the team found that science museums communicate the principles of science through hands-on and interactive exhibits. Museums develop these exhibits to provoke engagement and enthusiasm among visitors. Research shows that visitors gain more knowledge and excitement from hands-on and interactive exhibits than from traditional exhibits that may only display visuals and text. By offering outreach programs that complement classroom education, the Science Museum can help teachers increase their ability to teach scientific principles to students.

In order to help extend the Science Museum's Launch Pad gallery, the team followed several steps that led to successful development of three exhibit extensions: the Archimedes screw, electric motor, and electric generator. These extensions are activities that Key Stage 2 and Key Stage 3 students can construct on their own or in groups to display the scientific principles of movement, energy, and electricity. The team researched the most effective ways to create exhibit extensions. The team also researched and tested available hands-on activities and completed a decision matrix to choose which activities to further design. Then, the team constructed initial prototypes and instructions for the exhibit extensions. The team evaluated these prototypes through testing with museum staff, schoolteachers, and students. Based on the results of the evaluations, the team made the necessary adjustments to create final exhibit extensions.

The exhibit extensions affected three different groups: museum staff, teachers, and students. The extensions provided museum staff with additional resources that could be included in an online teacher resource and the museum's outreach box. These resources increased students' interest and involvement with the museum. The extensions provided teachers with demonstrations that complemented their science lesson plans and helped them to demonstrate scientific principles with confidence and ease. The extensions supplied students

with a new and exciting means of learning about science. The team also provided the museum with recommendations for future improvements to the extensions.

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1 Introduction

Museums have many purposes, including the conservation and presentation of information. Museums conserve information by conducting research and collecting artifacts. Museums display this information in exhibits and programs at the museum, as well as through outreach programs conducted outside of the museum. While exhibits have traditionally been text and observation based, museums currently develop hands-on and interactive exhibits that engage the users. These new exhibit types have proven to be more effective than traditional exhibits in conveying the information displayed by engaging visitors for an extended period. Museums aim to increase the ability of their exhibits to attract visitors, especially children, and aid in the learning process.

Based on an extensive review of literature on informal education (see Section 2 below), the team found that science museums are able to communicate the principles of science. Museums develop hands-on and interactive exhibits to provoke engagement and enthusiasm among visitors, since research shows that visitors gain more knowledge and excitement from these exhibits than from traditional exhibits that may only display visuals and text. While hands-on and interactive exhibits accomplish the tasks of teaching and exciting visitors, museums have developed ways to extend and enrich this experience for three primary audiences: those preparing for a visit, those who have already visited, and those who are unable to visit the museum. In order to reach these audiences, museums operate outreach programs, such as shows or activities completed in schools. While museums have geared outreach programs towards in-school shows or projects during the past, their focus now includes games and do-it-yourself activities available online.

The London Science Museum employs both hands-on and interactive exhibits in their Launch Pad gallery. This Launch Pad gallery is under renovation to increase not only its size, but also its ability to increase children's interest and knowledge in science. The museum aims to create an outreach program associated with the new Launch Pad gallery that reaches the three primary audiences of museums. As part of this outreach program, the Science Museum asked the project team to develop a set of exhibit extensions, which are hands-on activities that demonstrate the concepts presented in the gallery. Because the new Launch Pad gallery contains over fifty exhibits, it was not feasible for the team to complete an extension for each exhibit. Instead, the museum asked the team to begin by designing extensions that would demonstrate three principles: the Archimedes screw, electric motor, and electric generator. Teachers will use

the exhibit extensions to teach students scientific principles and complement lesson plans before, after, or in place of a museum visit.

The team conducted research to examine previous outreach programs. This research helped the team understand how museum staff and teachers defined success and what aspects of the programs did or did not make them successful. The team used this information to develop a set of prototypes and presented them to museum staff, teachers, and students. The team observed and questioned the users before, during, and after the construction and use of the prototypes. Based on this feedback, the team evaluated the prototypes and made the necessary adjustments to create final designs of the exhibit extensions.

2 Background

The London Science Museum aims to spread scientific knowledge and ideas to the public. One important audience that the Science Museum affects is children. Research shows that the level of knowledge and interest children have in science affects their continuation of a scientific education and career. For this reason, the Science Museum aims to boost both the educational performance of the students and their interest in science. The Science Museum uses hands-on and interactive exhibits to accomplish this goal. While these exhibits are extremely successful, visitors would also benefit from access to additional information. Such information is available through outreach programs that allow for education on the topics before and after visits, as well as providing information to those who cannot attend the museum. Outreach programs, especially those that are hands-on or interactive, are successful in not only increasing children's knowledge but also in improving their level of interest in and excitement about science. The London Science Museum uses these programs to aid Key Stage 2 and Key Stage 3 schoolteachers in following and reinforcing the National Curriculum requirements while inspiring students to explore and question scientific principles ("New Launch Pad," n.d.). While the Science Museum currently offers an interactive website and traveling outreach programs, they want to develop hands-on extensions that demonstrate the principles taught in the Launch Pad gallery.

2.1 National Curriculum

The United Kingdom’s Education Reform Act of 1988 established the National Curriculum that “sets out a clear, full and statutory entitlement to learning for all pupils up to the age of 16” (“About the National Curriculum,” n.d.). The Qualifications and Curriculum Authority (QCA) depicts, as shown in Figure 1, the arrangement of the education system and the different age groups of each key stage. In this project, the team focused on Key Stage 2 (KS2)

Figure 1: Key stages of the National Curriculum

Key stages

Age	Stage	Year	Test/Qualifications
3-4	Foundation		
4-5		Reception	
5-6	Key Stage 1	Year 1	
6-7		Year 2	National tests and tasks in English and mathematics
7-8	Key Stage 2	Year 3	
8-9		Year 4	
9-10		Year 5	
10-11		Year 6	National tests in English, mathematics and science
11-12	Key Stage 3	Year 7	
12-13		Year 8	
13-14		Year 9	National tests in English, mathematics and science
14-15	Key Stage 4	Year 10	Some children take GCSEs
15-16		Year 11	Most children take GCSEs or other national qualifications
16-17	Post-compulsory education and/or training	Year 12 (College Year 1)	Learning programmes leading to general, vocationally-related and occupational qualifications for example, A level, vocational A level, NVQ, modern apprenticeship
17-18		Year 13 (College Year 2)	
18-19			

Source: *About the National Curriculum*. (n.d.). National Curriculum online. Retrieved November 2, 2006, from <http://www.nc.uk.net>

and Key Stage 3 (KS3). KS2 includes students in years three to six of school and aged seven to eleven. KS3 includes students in years seven to nine, aged eleven to fourteen. The National Curriculum sets a standard of which educational subjects teachers should teach at each key stage and which subjects schools test at the end of each stage (“Key stages,” n.d.).

The National Curriculum online outlines that the study of science within these key stages must include scientific inquiry, life processes and living things, materials and properties, and physical processes. Students explore these topics while learning the skills that will help them reach the attainment targets. These targets are the necessary skill levels that students need to meet in order to pass a key stage set forth by the National Curriculum, as explained below (“Key stage 2,” n.d.).

During key stage 2 pupils learn about a wider range of living things, materials and phenomena. They begin to make links between ideas and to explain things using simple models and theories. They apply their knowledge and understanding of scientific ideas to familiar phenomena, everyday things and their personal

health. They begin to think about the positive and negative effects of scientific and technological developments on the environment and in other contexts. They carry out more systematic investigations, working on their own and with others. They use a range of reference sources in their work. They talk about their work and its significance, and communicate ideas using a wide range of scientific language, conventional diagrams, charts and graphs. (“Key stage 2,” n.d.)

Building on the skills learned in KS2, students in KS3 apply the basic principles to more complex and quantitative work. The students also learn to “evaluate their work, in particular the strength of the evidence they and others have collected....They learn how scientists work together on present day scientific developments and about the importance of experimental evidence in supporting scientific ideas” (“Key stage 3,” n.d.). The team ensured that the concepts presented to the students through the exhibit extensions met the National Curriculum standards.

2.2 Museums’ Role in Science Education

The London Science Museum is not unique in its aim to enhance the knowledge and excitement of students. The article “True needs, true partners” (2002) reports that American museums spent over a billion dollars on educational programs for K-12 students in the 2000-2001 school year. In an effort to interest more students in math and science, the museums are working in unison with the schools. The article reports that 71% of museum educational programs contacted and coordinated with school curriculum directors. Museums provide schools with an opportunity to experience the museum through a “wide range of programs and services from field trips and traveling exhibits to Web sites, videos and print materials” (“True needs, true partners,” 2002, p. 3). Along with these educational programs offered by museums, “83% of the U.S. Association of Science-Technology Centers (ASTC) members sponsored teacher education workshops for teachers already working in schools” (Pearson, 2002, p. 89). At these professional development workshops, the museums provide teachers with opportunities to learn about science, including new and interesting ways of applying scientific principles and demonstrations.

In today’s society, museums are among the many organizations that realize “there is a pressing need to promise scientific knowledge and interest for all students” (Paris, Yambor, & Packard, 1998, p. 1). Zoldosova and Prokop (2006) found that by interesting young students in science and engineering the students would be more likely to stay interested and pursue a career in these fields. Also, if students at a younger age do not become interested in subjects such as math and science, the United Kingdom could suffer in the future due to the lack of interest in

scientific professions that are necessary for technological advancement and economic growth (U.K. Department for Education and Skills, 2006).

2.3 Types of Education

Two different types of education are formal and informal. Formal education is structured learning completed by a teacher with a group of students, while informal education is unstructured learning that typically occurs outside of the classroom, such as at home or in a museum (“Informal science education,” 2006, Section I). One of the purposes of informal education is to deepen students’ understanding of particular topics. Another equally important goal is to develop a student’s interest in and excitement about the subject matter.

Some of the many differences between informal and formal education are identified in Figure 2. Most importantly, informal learning involves almost no structure and instead allows the participant to create his or her own experience with the information provided. In this type of unstructured atmosphere, students feel more relaxed and less stressed, which in turn allows them to choose to absorb more of the information provided (Remey-Gassert, 1997). When students choose what to learn about a subject, they will be more open minded and motivated to learn the material. Because of the lack of structure of informal education, its results vary and may include many unplanned outcomes. For this reason, it is very difficult to judge its direct result, especially on students’ test scores (Jorgenson, 2005).

Figure 2: Comparison of Formal and Informal Education

Informal [Education]	Formal [Education]
Voluntary	Compulsory
Haphazard, unstructured, unsequenced	Structured and sequenced
Non-assessed, non-certified	Assessed, certificated
Open-ended	More closed
Learner-led, learner-centred	Teacher-led, teacher-centred
Outside of formal setting	Classroom and institution based
Unplanned	Planned
Many unintended outcomes (outcomes more difficult to measure)	Fewer unintended outcomes
Social aspect central, e.g. social interactions, between visitors	Social aspect less central
Low 'currency'	High 'currency'
Undirected, not legislated for	Legislated and directed (controlled)

Source: Wellington, J. (1990). Formal and informal learning in science: the role of interactive science centres. *Physics Education*, 25, 247-252

Informal education can take place in a variety of different settings. One of the most popular settings is the museum. Over the past 40 years, informal education in museums has

developed from exhibits showing displays and texts to hands-on and interactive galleries (Wake, 1996). These exhibits provoke enthusiasm and involvement from visitors (Jorgenson, 2005). Interactive exhibits are becoming even more popular because they provide excitement similar to what hands-on exhibits offer; however, these exhibits also present informational feedback that encourages visitors to spend more time on a particular activity (Gilbert & Priest, 1997).

2.4 Evaluation of Informal Education

There have been many attempts to quantify the effect of inquiry science on standardized test scores (Jorgenson, 2005). For the most part, these attempts have been unsuccessful in demonstrating any correlation between the two. Few studies have considered the long-term effectiveness of informal education, especially in the area of hands-on education. This effectiveness is difficult to quantify because the testing requires an extended period and various results can occur. While not many specific case studies aim to prove the effectiveness of hands-on education methods, people generally accept that science museums are able to raise both the educational performance of students and their interest in science.

On a small scale, Zoldosova & Prokop (2006), Freedman (1997), and Knox, Moynihan, & Markowitz (2003) analyzed the effectiveness of informal education in classrooms, science centers, and field trips. Each study used two groups of students: one as a control group that learned through formal education and one that received the same information in an informal setting. The evaluators tested each group of students before and after the experience. These studies each concluded that there was an increase in knowledge when students learned through informal education in comparison to the control group.

Zoldosova & Prokop (2006), Freedman (1997), and Knox, Moynihan, & Markowitz (2003), measured the interest level of students after completion of the informal learning program. Then, they compared the interest levels of these students to those of a control group who experienced the same information through formal education. They found that the interest levels of those students learning through informal education were higher than the interest levels of the students in the control group. Zoldosova and Prokop (2006) analyzed interest levels of younger students by asking them to draw an ideal learning environment. The group that participated in this informal education study drew devices related to the informal setting to which they were exposed. These drawings show that the devices used in the informal setting were effective at increasing the interest of students.

Gilbert and Priest (1997) conducted a study of a primary school visit to the London Science Museum and identified certain factors that optimize the amount of knowledge and

interest students gain during informal activities. The study found that students feel most comfortable exploring information when they do not have a set lesson plan or feel pressured. Small groups of students who have the freedom to experience the exhibits and activities as they choose are more successful in gaining knowledge and interest about the subject matter. It is also beneficial to have a knowledgeable adult with each group of students to help answer questions or guide the discussion as needed.

2.5 Hands-on Education

Traditionally, interactive exhibits involved physical, hands-on activities such as pouring water, pulling levers, or arranging objects, but more recently, there has been a trend towards the use of online instructions, computer games, and multimedia demonstrations (Bradburne, 1996; Wake, 1996). Wake (1996) states that one of the most common forms of digital learning that museums develop is the interactive gaming experience. Interactive games are becoming very popular and are sometimes the highlight of the museum experience. Although these games are a very good source of entertainment for the users, they also have the ability to present information effectively. Another popular type of informal education utilizes multimedia outlets, including simulators and movies (Wake, 1996). IMAX and 3D simulators are good examples of these outlets.

Many experts in this field believe that museums need interactive exhibits, especially those involving multimedia, in order to maintain their audiences (Bradburne, 1996). According to a test done by Ayres, multimedia exhibits proved to be more effective than physical hands-on exhibits that explore the same subject area (Ayres & Melear, 1998). However, multimedia does not most effectively teach all scientific principles (Bradburne, 1996; Wake, 1996). Students have the best experience with exhibits when they are hands-on, such as when the students can feel the magnets or hear the sound of electricity charging. For this reason, the London Science Museum's Launch Pad gallery currently includes hands-on and interactive exhibits in the museum, as well as multimedia displays available online. In order to incorporate these methods into their new Launch Pad outreach program, the team designed several hands-on or interactive exhibit extensions.

2.6 Outreach

Most science museums offer a variety of outreach programs to complement their exhibits and extend their intellectual and geographic reach. For example, the Museum of Science in Boston encourages students "to discover science in an entertaining, educational, and

interactive way” through its outreach programs (“Learning resource,” para. 1). The Boston Museum of Science’s webpage describes one program called a “Camp-in” which works to accomplish this task. During this program, the children stay overnight in the exhibit halls and participate in activities after-hours. These activities include science demonstrations, various hands-on activities, an Omni Theater show, and group exploration of the museum. Along with “Camp-ins,” the Boston Museum of Science also offers lectures, traveling exhibits, and a science van that transports the necessary materials for demonstrations and hands-on experiments (“Learning resource,” 1999). The Science Museum in Virginia has a similar Science-by-van program that travels to schools and leads children through a full day packed with science activities, including presentations offered by two instructors, a 20-minute all-school assembly demonstration, classroom workshops, take-home experiments, and hands-on exhibits (“Science-By-Van,” 2006).

The Center for Informal Learning and Schools (CILS) is a collaborative outreach program developed by the Exploratorium in San Francisco, King’s College London and the University of California Santa Cruz. CILS supports the improvement of K-12 science education through the study of informal science learning (“Center for informal learning and schools,” n.d.). Like many other museums, the Exploratorium has a range of educational materials that are available online for members of the public, teachers, and students. For example, the Exploratorium’s Field Trip Pathways (n.d.) offers hundreds of virtual experiments for children and safe do-it-yourself experiments for use in the classroom or at home. There are also various guided tours for teachers who are planning field trips to the museum. The teachers can choose the best path through the museum that will fit what their students are learning about in school. Many science museums offer virtual tours, like those offered by the Exploratorium, where children can learn about science and the exhibits of a museum in the comfort of the students’ own homes (“Field trip pathways,” n.d.).

It is possible to evaluate outreach programs in a variety of ways using both qualitative and quantitative measures. For example, qualitative measures evaluate feedback from student, teacher and parent focus groups, or samples of students’ work. Quantitative measures include students’ performances on tests, attitude surveys, and student, teacher, and parent surveys (Rudy, 2001). Evaluation of outreach programs is an extensive and time-consuming process. It can take many years depending on the program and the desired depth of analysis (Rudy, 2001; Marty, Sheahan, & Lacy, n.d.).

The London Science Museum recently completed a large-scale outreach program that included thirteen schools and more than 380 children. During the course of the program

students learned about energy through classroom sessions, school performances, and a filming project. The museum then conducted an evaluation of the outreach program. The evaluation committee interviewed seven teachers, conducted three focus groups of students, and took notes during the sessions. The museum concluded that those that participated in the outreach program “had experienced personal and social learning during the project, as well as cognitive learning” and “[s]ome teachers stated that the project had stretched their pupils learning well beyond what would normally occur in the classroom” (Jenkins, p. 4).

Because it is difficult to conduct high quality evaluations, there is a gap in the research on the long-term effectiveness of outreach activities. However, some museums have measured the short-term effectiveness of their outreach programs. For example, the Oregon Museum of Science and Industry measured the effectiveness of their Dangerous Decibels outreach program. The Oregon Museum of Science and Industry introduced this program to fourteen fourth-grade classrooms. The external evaluation team gave teachers and students pre and post questionnaires, as well as conducted three small focus groups of students and teachers. The Oregon Museum of Science designed the study to determine “the effectiveness at improving knowledge and effecting changes in attitudes and behaviors of young people related to noise-induced hearing loss” (“Outreach program overview,” n.d., p. 1). The feedback and results of the evaluation showed that the program was effective, thus contributing to its implementation and expansion. The program is now available to first, fourth, and seventh grade students in Oregon and the Pacific Northwest (“Outreach program overview,” n.d.).

3 Methodology

The goal of this project was to develop classroom activities that accurately demonstrated certain scientific principles portrayed in the Launch Pad gallery. Each of these demonstrations contained the “wow” factor, or aspects that students found impressive and memorable. They were visually engaging, exciting, and safe. These activities supported teachers and students who planned to visit, have visited, or were unable to visit the Launch Pad gallery, as well as supplemented the material taught in the classroom as outlined by the UK National Curriculum. In order to attain this goal, the team developed several research questions.

- What constitutes the success of a program?
- What programs were or were not successful in the past and what are the key elements that determine success?
- What aspects of hands-on exhibits, including Launch Pad, contribute to excitement and learning?

- What are the needs and expectations of the museum staff, teachers, and students?
- What are the educational purposes of the Launch Pad Extension Project?

In answering the research questions outlined above, the team created the most effective demonstrations for students. The first research question asks what constitutes the success of a program. Various people measure success in many different ways. For example, the museum may consider a program successful if a certain number of individuals subscribe to the program, but teachers may consider a program successful if their students learn from it. The measures of success vary depending on the goals and expectations that different people have for the program. The team interviewed schoolteachers and museum staff in order to understand their measures of success, as well as how they evaluate each measure and consider it for incorporation into the project.

The second research question addresses the success of past programs. The programs include outreach and the Launch Pad gallery offered by the London Science Museum, along with past programs and outreach offered by other museums. The team answered this question by interviewing the liaisons, selected teachers at local schools, and staff at the Science Museum. The team incorporated the successful aspects of past programs into the designs, while avoiding the mistakes that led to program failures.

The third research question is very important because it addresses which aspects of exhibits contribute to excitement and learning of students. The team took into consideration the Launch Pad gallery and other hands-on exhibits through observation, interviews with museum staff, and recording the responses of students to the presentation of prototypes. It was important to identify what aspects excited students, interested them in learning, and left a lasting impression. The team incorporated these successful aspects into the demonstrations in hopes of having the same effect on students.

The next research question addressed the needs and expectations of museum staff, schoolteachers, and students. The team answered this question through interviews with teachers and museum staff. In knowing what the participants hope to gain, the team considered and incorporated their needs into the prototypes throughout the design process.

The last question asked what the educational purposes of the Launch Pad extension project are. It was important to know the educational purposes to ensure teachers would be able to integrate the project into their lesson plans. The team gained this knowledge through the literature review and meetings with selected museum staff and teachers. The team needed to know how the demonstrations would fit into the educational level and curriculum requirements so that they may effectively supplement the students' learning

In order to answer these research questions, the team continued research into informal education, outreach programs, and their effectiveness. The team also conducted interviews, developed prototypes, and evaluated these prototypes. Evaluation included observations of prototypes in use, surveys of users, and subsequent analysis. After acquiring the information during the evaluation phase, the team adjusted the prototypes to complete final exhibit extensions.

3.1 Proposal Presentation

Once in London, the team gave a presentation to selected staff at the London Science Museum. This presentation served as an introduction to the sponsor. It not only formally presented the team for the first time, but it also described the expected path of the project. The team communicated their ideas and goals to the sponsor. This presentation began conversations with the sponsor that provided the team with further direction in the project.

3.2 Meetings with Museum Staff

Following the presentation of the group's proposal to the sponsor, the group attended several meetings with selected museum staff. At these meetings, the team and museum staff discussed topics such as the goals of the outreach programs, attributes that have contributed to the success of outreach programs in the past, measures and evaluations of the success of the programs, and aspects that students enjoy the most about museum exhibits. During some of these meetings, the team observed prototype testing and evaluation. Other meetings involved the development and evaluation of outreach programs, as well as the development of the new Launch Pad gallery. The team also learned about what teachers are hoping to gain from the Launch Pad extensions. Other meetings included inquiries into the evaluation process, as well as observations of the museum's outreach programs.

3.3 Teacher Advisory Panel

The Science Museum works with a Teacher Advisory Panel that is comprised of nine KS2 and KS3 teachers. This panel helps the museum evaluate prototypes and ideas for future outreach programs. At a meeting of this panel, the team presented prototypes to the teachers and gave each teacher the opportunity to construct his or her own prototype. The team's schedule can be found in Appendix B. The team discussed with the teachers the positive and negative aspects of the prototypes, along with suggestions. The team documented the

proceedings with notes, audio and visual recordings, and transcriptions. The team’s observation form and questions can be found in Appendices C and E. The teachers then brought the prototypes, along with supplementary instructions and templates, to their classrooms as described in section 3.5.

3.4 Design

The museum staff supplied the team with a list of guidelines for the designs. From these general guidelines, the team brainstormed possible prototypes and then began web research into previous designs for each concept. The team tested designs found on the internet to see if the designs were successful or if they required improvement. After initial testing, the team developed distinct design specifications for each extension. Using these specifications and ideas generated from web designs, the team worked together to design the initial prototypes.

To choose a design to prototype, the team created a set of categories on which to rate each design. These categories consisted of safety, cost, aesthetics, ease of use, ease of assembly, ease of sourcing materials, educational purpose, length of demonstration, and “wow” factor. The team organized a matrix with all of the categories on the left side from top to bottom and the top from left to right. Next, the team compared each category on the left to each category on the top. When the category on the left was more important than the category on the top, the team placed a one in the square in which they intersected. When the categories were of equal importance, the group inserted a one-half in the square. When the category on the left was less important than the category listed on the top, that category received a zero for that square. After all the squares were completed, the team added the numbers up for each row and placed totals at the end of each row. This number, when compared with the sum of all the numbers, gave the weighting percentage for that category. Since all the designs had common guidelines, the team only needed to make one pairwise comparison chart. The team’s pairwise comparison is in Appendix I.

After completing the pairwise comparison, the team created an objective system in which to rank each design. For example, when ranking the cost of a design on a scale from one to ten, a one described a design costing more than what was reasonable, a five meant a cost that was appropriate, and a ten described a design that cost much less than what was expected. Once each category had a weighted value, the team took each preliminary design and gave it a specific ranking, from one to ten, on how well it fulfilled the specified tasks. This ranking system can be seen in Appendix J. The team put these rankings into a decision matrix. This matrix listed the designs in the first column and the design criteria in the first row. The team used the weights

from the pairwise comparison to weigh the numbers from the ranking system. The team summed the numbers in each row and determined that the design with the largest final value was the best design choice available. The team's decision matrices can be seen in Appendix K.

After the team found the best design according to the decision matrix, the team built each prototype and tested them. The team then improved upon each design. These improvements reduced cost, made the components easier to procure, worked out any kinks in the current design, and added exciting extensions. The team's cost analysis can be seen in Appendix W. Once these prototypes were complete, the team created instructions for the prototypes and began testing. The results of the design process can be seen in Appendices H, I, and J.

3.5 Evaluation through Observation

At the Teacher Advisory Panel described in section 3.3, the team provided teachers with prototype instructions. As part of a lesson plan, the teachers had their students create the prototypes using the instructions. The team asked the teachers to take pictures, fill out a feedback form, and return that information via email. The team developed the feedback form after meetings with the Science Museum's evaluation team. This form can be seen in Appendix G. This evaluation helped the team to understand what students and teachers expect from the extensions.

Presenting the prototypes in both the museum and classroom was very important in determining the effectiveness of the initial prototypes. The Science Museum granted the team permission to evaluate the prototypes in the museum by observing the interaction of visitors with the prototypes. The team tested the prototypes with members of the museum staff and KS2 and KS3 students who had verbal consent from their guardians. To help with the evaluation process, the team developed the observation forms seen in Appendices O, Q, and T. These forms gave the observer a better understanding of what to look for, and made the process more organized and simple. These observations provided the team with possible improvements for future designs. The team asked those who tested the prototypes questions to understand their grasp of the demonstrated principles and thoughts of the prototypes. The main goal of these questions was to gain "insight into how to make improvements in the exhibits that will help people's interactions and understanding" (Diamond, 1999, p. 58).

Once the team collected the observation and interview data, the team evaluated and analyzed the results to determine the effectiveness of the prototypes. The team read the interview responses to understand which elements of the prototypes the users understood.

These responses included suggestions about the prototypes and what improvements the team needed to make. The team evaluated the responses to questions and used the frequency of positive and negative feedback to determine which aspects of the designs were or were not successful. When answering questions, users tend to provide a positive or neutral response because the users feel that if they answer with a negative response that they will offend the designers of the prototype. For this reason, the team assured the users that all answers would be helpful and not offensive. The team also weighed negative answers more heavily in the evaluation process. The evaluation suggested the necessary changes for the final design to be successful.

3.6 Conclusion

Through the background research and methodology outlined above, the group created successful exhibit extensions to the Launch Pad gallery. These prototypes extended the reach of the Science Museum and helped develop students' interest and knowledge in science. The team obtained this result through complementing the formal classroom setting.

4 Results and Discussion

4.1 Research Questions

Through meetings with museum staff and schoolteachers, as described in Sections 3.2 and 3.3, the team answered the research questions outlined in Section 2, such as how the museum defines and measures the success of a program. One way a program is successful is when visitors become excited about an exhibit or demonstration in that program. The Science Museum also defines success as when a visitor remembers one part of an exhibit or demonstration because he or she sees something so great that the memory remains. For example, a student may come to the museum and see one of the Launch Pad gallery shows. Ten years from now, that student may not remember all of the different principles taught, but because he or she remembered an exciting aspect of the show, it was a memorable program and therefore successful. If a prototype has an exciting or memorable aspect to it, then the prototype does not necessarily have to incorporate the scientific principle to be successful.

A program is also successful when a visitor learns from interacting with the program. Many times, visitors have a moment of realization that occurs when they understand the main principle of the exhibit or demonstration. For instance, a person reads the instructions for an exhibit and begins to interact with it. Up until one point, this person might be confused and not

understand the demonstrated phenomenon. However, there is a moment when he or she realizes the principles demonstrated in the exhibit. The Science Museum refers to this instance as a “eureka” moment and believes that it is another indication of success. These definitions of success are difficult to quantify because they do not provide a measurable response. For this reason, the museum uses facial expressions, body language, and oral responses, to measure the user’s excitement and learning.

The team found several factors that helped to create exciting and educational exhibits and programs. Some of these factors include explosions, disgusting effects, group activities, and humor. The Launch Pad gallery is especially popular because it displays all of these factors. One exhibit allows students to pump bubbles up tubes of different colored slime. Each tube of slime has a different viscosity, which causes the bubbles to travel up the tubes at different speeds. Another exhibit allows students to go into a cube where they can press a button, pose, and leave a shadow on the wall behind them. For this exhibit, the kids will often have fun by doing a funny pose alone or in groups.

By researching past programs completed by the Science Museum, the team learned about previous failures. The team found that exhibits with cluttered interfaces and unclear directions confused visitors since they did not understand the exhibit’s purpose. The Science Museum fixed these problems by minimizing the number of options on the interface, narrowing the scope of the exhibit, and developing clear exhibit labels. These adjustments provided visitors with a purpose for the exhibit, as well as a clear understanding of possible interactions with the exhibit. The team also found that without prototype evaluation it is difficult to predict the success of an exhibit due to visitors interacting with exhibits in unexpected ways. For this reason, it is extremely important to create prototypes, evaluate them through observation and questioning, analyze the results for possible improvements, and complete these improvements before the museum approves of the finalized prototypes.

The team also researched the needs and expectations of the three major groups affected by the extension project. These three groups were museum staff, teachers, and students. The team needed to know their needs and expectations in order to create a clear focus for the project. This focus helped the team to create designs that satisfy as many expectations as possible, so that the designs may be useful for all the groups involved. Even though some expectations differed among each group, the groups also shared some expectations. Even though these common expectations were the minimum standard that the designs needed to achieve, the team also strived to achieve the additional expectations for each group.

These common expectations included designs that are exciting, educational, and safe. In many instances, the exciting element or wow factor of a design intrigued and motivated students to investigate further. Through this investigation, students learned the scientific principles demonstrated in the designs. Safety was also an important consideration; however, it was necessary to take small risks, such as chance of sparks, hot wire, or staining, in order to achieve the wow factor. The team evaluated these risks on a case-by-case basis, depending on the scenario and type of risk. If the team and museum staff deemed a risk acceptable, the design instructions included appropriate precautions that the user should follow in order to minimize this risk.

In addition to the general expectations, each group had its own unique expectations. The museum staff expressed the need for the designs to interest students in the museum, link back to the Launch Pad gallery, and support teachers who do not have specialized training in the sciences. The museum also wanted the extensions to appeal to KS2 or KS3 students. The teachers interviewed by the team wanted the designs to fit into the National Curriculum, be easy to complete without extra research, and use inexpensive and easily sourced materials. Finally, the museum staff and teachers stated that students expected the designs to be more interesting than the students' everyday classroom experience.

The needs and expectations outlined by museum staff and teachers reinforced that designs must have educational purposes. These purposes included providing teachers with the information and resources needed to teach the principles, teaching students scientific principles outlined by the National Curriculum, and interesting students in science.

4.2 Design Results

Once the team answered the research questions, which gave the project a clear focus, the team began the design process outlined in Section 3.4. The team began by reviewing previous museum staff research findings on the scientific principles taught by the extensions and the demonstrations currently available. The team then used the internet to research the principles and available materials, products, and demonstrations. After the team completed a full review of the museum's findings and available online resources, the team ranked all of the designs and completed decision matrices, as described in Section 3.4. The team then developed the designs that scored the highest in the decision matrices into the initial prototypes.

4.2.1 Archimedes Screw

Through research compiled by museum staff, the team found that the Archimedes screw

should demonstrate that machines can reduce the force required to move an object. The Archimedes screw is an incline plane wrapped around a cylinder. The Archimedes screw is a simple machine that exhibits the idea of mechanical advantage, which refers to how much easier and faster the work is using the Archimedes screw (“What is mechanical advantage,” n.d.). Archimedes first developed the screw in the third century BC, and people primarily used it for transporting water for irrigation. A person would place the lower end of the Archimedes screw into the river and rotate it. In turn, the water would travel from the river up through the screw to another source on land. In today’s society, companies use the Archimedes screw for processes such as irrigation and grain transport. The Science Museum uses the concept of the Archimedes screw as part of the “Big Machine” exhibit in the Launch Pad gallery.

The museum findings also provided the team with two initial design ideas from an internet source. The team continued researching with the internet and was unable to find homemade demonstrations that differed from those provided by the museum staff. However, the team found pre-made products in several educational catalogs for teachers to purchase and use as a demonstration. While the pre-made products were fully functional, they prevented the students from constructing the extensions themselves. If the students do not construct the extension themselves, they will not fully experience the connection between components of the design and therefore will not completely understand the principles taught.

The first of these two initial prototype designs was the tube Archimedes screw. The demonstration involved a length of flexible, plastic tubing wrapped around and secured to a wooden dowel (Valadares, 2005). When the user placed the dowel in water and rotated the screw, the water should have traveled up the tubing and exited at the top. The team found that wrapping the tube around a small dowel caused the tube to become constricted and water was unable to pass through the tube. For this reason, the team chose to use a two-liter plastic bottle, instead of a wooden dowel, so that the tube would not constrict, as shown in

Figure 3. This new system allowed the water to flow freely through the screw; however, since the water and tubing were both transparent, the user was unable to view the result clearly. To increase the effect of the prototype, the team added food coloring to the water so that the liquid was more visible through the tubing.

Figure 3: Tube Archimedes Screw



The second of the initial prototypes was the paper Archimedes screw. The prototype used cardboard cut into circles, taped into a spiral, and secured around a wooden dowel to create a screw shape. A plastic bottle with the ends cut off then covered the wooden dowel and cardboard spiral (“Archimedes’ screw,” n.d.). The museum staff constructed a version of this prototype and presented it to the team. After examining this prototype, the team discovered several flaws in the design that involved the diameter of the circles compared to the diameters of the wooden dowel and the bottle. To find more information on these flaws and understand why the prototype was not working, the team followed the same instructions and constructed their own model. Through the prototype, the team evaluated what was wrong with it and recognized different methods to fix the flaws. After working out all of the flaws through experimenting, the team developed a prototype that worked well and was robust enough for kids to construct and use. This prototype is shown in Figure 4.

Figure 4: Paper Archimedes Screw



Once the prototype functioned properly, the team tested how well the prototype transported different materials, such as plastic pellets, rice, and split peas. Unfortunately, the rice did not travel up the screw well, because it slid back down the spiral. However, both the plastic

pellets and split peas easily traveled up the length of the screw. The team chose the split peas as the preferred material, because they are inexpensive and easily sourced from most grocery stores.

In order to increase the visible result of the prototype, the team created an expanded version of the Archimedes screw that was one meter long, compared to the thirty-five centimeter long original extension. The goal of the expanded screw was to transport the materials a longer distance in order to excite the students and provoke further investigation of how to use this principle in their everyday lives.

4.2.2 Electric Motor

To begin research on how to demonstrate this principle, the team looked at documents compiled by museum staff, which stated that the electric motor must demonstrate the ability of electricity to produce movement. An electric motor contains a coil of wire that has an electric current running through it, which creates a magnetic field that repels the coil away from a stationary magnet. By having current pass through the coil only half the time, the coil will push itself through its revolution and the coil will spin continuously to create a motor. Many household appliances use electric motors, including fans, refrigerators, and washing machines.

One of the activities discovered through museum research identified a design that created a small electric motor from magnets, copper wire, a battery, paperclips, and a plastic cup (Shakhashiri, n.d.). Through the team's research in educational supply catalogs, the team found many relevant materials, such as magnets and wire, but the only activities available were kits consisting of pre-assembled materials (Harris, 2003). Since the kits did not allow the students to create the motor themselves, the students may not understand the principles. These kits were also unrealistic for a classroom activity because the cost of each kit was £25 and might exceed the average teacher's budget. The team also researched through the internet, where similar electric motor kits were available ("Motor model experiment set," 2005).

Through further internet research, the team discovered demonstrations similar to the design provided by previous museum research. For example, Energizer's "Science project" website described a design, which used different materials to create an electric motor. This design required the use of wood, a cork, a needle, a switch, wire, magnets, and clay ("Make an electric motor," 2006). The last design found through web research was entitled "10 minute motor." This design used fewer materials than that of the Energizer design; however, the steps for the "10 minute motor" involved very complicated set of instructions. These steps also involved precision bending of wires that may be more difficult for younger students (Field, n.d.).

Once the team understood many different ways to demonstrate an electric motor, the team completed a decision matrix. The decision matrix showed that the design previously researched by the museum was the best choice. The team modified this design by trying different materials than those suggested. The team created a list of easily sourced materials that were effective in the design and constructed the initial prototype seen in Figure 9. This design consisted of a wire wound into a coil. The coil had two tails, or spare ends, that were opposite each other on the coil. The instructions directed the user to strip one of the coils of its enamel completely, while only strip the top half of the other tail. This allowed the coil to receive the electric current only half the time and the motor to spin. The coil rested on two paperclips taped to the middle section of a cut plastic bottle. The top of the plastic bottle sat inside the middle of the cut bottle and supported a magnet. The battery connected to the paperclips to supply the electric current to the coil. A small initial spin of the coil completed the circuit, and the current moving through the coil produced a magnetic field. The magnetic field pushed the coil until the insulating enamel broke the circuit and cut off the current. The coil continued to spin, because its momentum rotated it until the bare half of the coil tail once again contacted the paperclip and completed the circuit. While the initial prototype functioned properly, the team recognized a few flaws in the design. Primarily, the team observed that the design produced small sparks and smoke. By modifying the materials used and the construction process, the team created a safe prototype that functioned properly.

Figure 5: Initial prototype

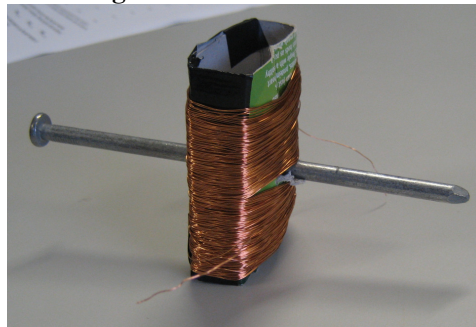


4.2.3 Electric Generator

As with previous prototypes, the research materials provided by museum staff specified that the electric generator must demonstrate the use of movement to produce electricity. An electric generator contains magnets spinning inside a coil of wire. The spinning magnets create a changing magnetic field and thus create an electric current in the wire coil. The current can then power items such as a light bulb.

The museum's research material also included the "Ultra-simple electric generator." This design combined enameled copper wire wound around a cardboard frame with magnets attached to a nail in the middle of the cardboard frame. When the nail is spun, the magnets spin and produce power (Beaty, 1996). Museum research also provided the team with a build-your-own generator kit. Unfortunately, this design kit required very little construction by the user. Therefore, this design did not effectively teach the scientific principle because the students would not have to assemble the design themselves and could not experience how the components interacted with each other to produce the result. Through web research, the team found similar electric generator kits; however, no homemade activities were available ("Action lab 4-in-1 kit," 2005). The team completed a decision matrix that concluded that the demonstration provided by the museum's research was the most effective way to teach the principle. The team tested this design to complete the initial prototype seen in Figure 6.

Figure 6: Electric Generator



The team determined that another way to demonstrate the principle of an electric generator was to create a flashlight, known as a torch in the UK, using the same principles. This flashlight is shown in

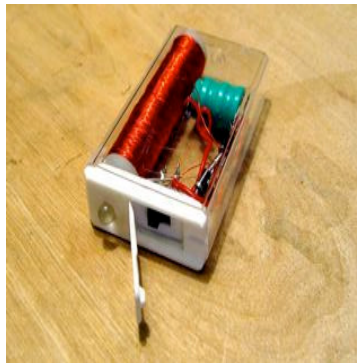
Figure 7 below. The team based the idea for this flashlight on previously viewed commercial products, which contain a magnet that travels up and down inside a tube coiled with wire. This movement produces an electric current that turns on a light bulb. The team's first design was a simple flashlight that consisted of a tube used to house the magnet, wire coiled around the outside of the tube, and a light bulb placed on top of the tube. The team later realized that because the flashlight required constant motion to light the bulb, the user would have to shake it constantly and at a consistent speed. The team discovered that if you are shaking the flashlight it is hard to focus the light on anything particular. The team decided to place the light bulb in a separate tube that connected to the container housing the magnet with insulated wire. Therefore, the user could shake the magnet tube in one hand while holding the other tube. This would provide a steady light beam.

Figure 7: Electric Generator Flashlight



The team discovered an idea similar to the simple tube flashlight ideas described above. This flashlight, shown in Figure 8, housed all of the parts inside a Tic-Tac container and allowed for a small, portable design that students could take anywhere (MrMunki, 2006). The team modified the design so that the generator components were inside the Tic-Tac container, while the light bulb and its housing could be either inside or outside of the container. When the flashlight was not in use, the container stored the light bulb; however, the user could remove the light bulb and its housing and shake the flashlight so that the light bulb emitted a steady beam, as in the previous design.

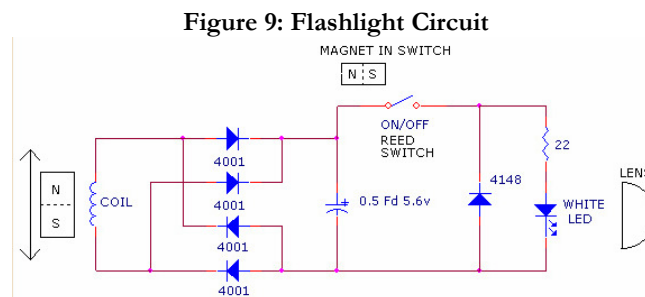
Figure 8: Tic-Tac Flashlight



Source: MrMunki. (2006). *Shake it like a tic-tac!*. Retrieved January 18, 2007, from <http://www.instructables.com/id/E5BLCRZ178ES9J6A88?ALLSTEPS>

The team encountered many problems with all three electric generators. The first problem was that the generators produced alternating current (AC). While alternating current can power a conventional light bulb, the generator did not produce enough energy to power a conventional light bulb. Because of this, the team needed to use a light emitting diode (LED), which requires much less power. When powered with AC, an LED flickers because it only allows current to travel through it in one direction. By definition, AC is current that alternates direction, and therefore, the LED only lights when current is flowing in the proper direction. This creates a flickering light that is not sufficient for a flashlight. In order to increase the

effectiveness of the flashlights, it is necessary to use circuit components. This circuitry, seen in Figure 9, allows the energy produced by shaking to be stored in a capacitor and then used to power the LED when a switch is turned on. The circuitry also converted the current to direct current to provide the LED with constant power and avoid the flickering. Since the flashlight requires shaking, the circuitry must have sturdy connections to ensure that the components will not shake loose. The most efficient way to connect the components is to solder them together, which requires some experience and equipment to complete. Since the flashlight contains strong magnets and circuit components, the materials are not easily sourced or inexpensive. For this reason, the design may not be feasible for students to construct themselves. Due to these problems, the team was not able to complete a prototype for testing; however, recommendations for further development have been included in section 6.



Source: Johnson, D. (2005). *Shake to charge flashlight*. Retrieved January 18, 2007, from <http://www.discovercircuits.com/forum/showflat.php?Cat=0&Number=2561&an=0&pag>

4.3 Prototype Instructions

After making improvements to the initial prototypes, the team developed a set of instructions for each. The team chose a bright and colorful template in Microsoft Publisher that would appeal to students. These instructions are clear and simple so that students will easily understand the procedure. The instructions use large text that is easy for students to read and a section listing the necessary materials and construction steps with corresponding pictures in separate columns. Included in the instructions is a labeled picture of the materials that corresponds to the list of materials. This will aid students in identifying the proper materials to use in the construction process.

4.4 Prototype Evaluation

After the development of initial prototypes and their instructions, the team conducted tests with several different groups of users: museum staff, teachers, and students (see

Appendices G, O, Q, and T for observation forms). Using the evaluation methods described in Section 3.5, the team tested the prototypes and instructions. The users provided the team with valuable feedback and suggestions on how to improve the prototypes and their instructions. Throughout the evaluation process, the team made improvements based on this information. The final results of this evaluation are described below, see appendices D, F, H, P, R, S, U, and V for complete details and observation notes.

Through the evaluation of the tube Archimedes screw, the team learned that the instructions were clear and that the construction process was simple for the users to complete. The prototype clearly demonstrated the principles; however, the results did not excite the users. To fix this problem, the team included in the note section of the instructions a suggestion to use plastic tubing with a larger diameter; this way, more water might be able to flow through the screw and the user may see a more exciting result. The instructions also suggest for the teachers to institute a challenge or competition with the students. This competition could entail having students use the tube Archimedes screw to see who could transport the most amount of liquid from one bucket to another bucket in the least amount of time.

The team found that the construction of the paper Archimedes screw was difficult for young students to complete on their own; however, the team felt that some supervision and explanation from teachers would resolve this issue. The team also found the instructions to be easy and exciting for most students to complete. The users displayed excitement when their prototypes functioned properly. The users felt that the expanded model was suitable for the classroom and would be beneficial for the students to see or use themselves.

Based on the results of the electric motor evaluation, the team found that the instructions were generally clear, but some tasks were difficult to complete. All of the users had difficulty stripping the enamel from the wires. They were unsure if they had finished the stripping process because they could not distinguish between enameled and stripped wire. The team found that the users were excited when their motor ran properly, but that they were disappointed by the inconsistent results produced by poor wire stripping. In many cases, the users constructed the motor almost perfectly, but because they did not strip the wires correctly, the motor did not run. After making the necessary changes to each prototype, the team created final exhibit extensions that include a set of instructions for each extension. These instructions are shown in Appendices L, M, and N.

4.5 Finalized Instructions

Through research and testing, the team made the final instructions that include several factors that make them successful. The team added investigation questions that challenge the user to investigate the topics presented through the extensions. The notes page includes warnings, scientific principles, expansion ideas, and alternative materials. The purpose of this page is to aid the users in constructing the extensions. The warnings introduce aspects of the extensions that might be dangerous, such as the electric motor wires increasing in temperature when attached to a battery. The scientific principles explanation will aid the user in understanding the concepts behind the extension. The expansion ideas provide suggestions for ways to extend the activity to increase the wow factor and promote further investigation. The instructions include a section suggesting alternative materials that can replace the listed materials.

5 Conclusions

The team's project aimed to increase students' interest and knowledge in science, as well as support teachers. To obtain this goal, the team developed three exhibit extensions that demonstrate some of the principles taught in the Launch Pad gallery. These extensions were the Archimedes screw, electric motor, and electric generator. Through evaluation, the team found important factors that the extensions must have, such as simple instructions that are easy to read and understand. The instructions must also include a construction process that is easy for students to follow. The extensions must clearly demonstrate the principles to ensure that the students are able to understand them. Once the students have constructed the extension, they must see an effect that will excite them. The team incorporated these important aspects into the final extensions. The museum staff will review these final extensions and use them as part of the Launch Pad Outreach Box and Online Teacher Resource, which complement classroom education. They will become available to schools after the completion of the new Launch Pad in November 2007.

The exhibit extensions affect three different groups: museum staff, teachers, and students. The extensions not only provide museum staff with resources for these programs but also increase students' level of involvement and interest in the museum. The extensions support teachers by providing them with demonstrations that complement their lesson plans and helping them to demonstrate scientific principles with confidence and ease. The extensions supply students with a new and exciting means of learning about science. After completion of the extensions, the team developed recommendations to aid future work in the Science Museum.

6 Recommendations

Recommendation 1: Design Process

The team recommends that future museum staff designing exhibit extensions for the Science Museum's online resource and outreach box complete a thorough investigation of pre-existing designs. This research should include the use of educational catalogs, previously compiled museum documents, and internet resources. Using the information and instructions found through research, the museum staff should then construct the activities. By doing this, the museum staff can identify positive and negative aspects of the activities. The museum staff should then improve the activities or apply the information learned to original design ideas to create final extensions.

Recommendation 2: Instructions

The team recommends creating clear and simple instructions that contain large text, steps listed in chronological order, and pictures that correspond to each step to explain the construction process. In addition, the materials must be easy to identify and clearly labeled in a picture of all materials. The instructions must also include a page of notes detailing the scientific principle, safety warnings, expansion ideas, and possible replacement materials.

Recommendation 3: Extension Use

The team recommends that the museum staff encourage teachers to incorporate the extensions into their lesson plans. The lesson plans will provide students with background knowledge on the principles and allow them to understand the extension concepts more easily. Also, the extensions will excite the students and encourage them to investigate further into the principles taught in the lesson plans.

Recommendation 4: Expansion of Extensions

In order for the extensions to be more successful, the team recommends linking the different scientific principles displayed in each extension. This link could include having one extension demonstrate two principles, such as an extension that is both an electric generator and an electric motor. This link might also include having two different extensions work in unison to create one or more results. For example, the Archimedes screw empties materials into a cup that weighs down a plunger to shoot off a pressurized air rocket. To link the prototypes together, the

students would have to use their understanding of the principles and their imagination to think creatively.

Recommendation 5: Exhibit Extensions

While the developed extensions are successful, the team recommends changes to increase their effectiveness. For the electric motor, the team recommends finding an improved method for stripping the enamel from the wire coil. This will simplify the construction process and help prevent students from becoming frustrated. The electric motor should also include a more significant wow factor to increase the interest level of older students.

The team recommends that teachers use the tube Archimedes screw as a demonstration. Because the construction of this extension is so simple, the teachers should construct the screw themselves and present it to the class as an introduction or conclusion to the lesson plan. To achieve a more exciting result, the team recommends testing the use of plastic tubing with a diameter larger than eight millimeter. The team recommends that teachers use the paper Archimedes screw as a classroom activity that the students construct and demonstrate themselves. By constructing the extension themselves, the students will understand the principles in greater depth since they will see each component and how they work together. This will cause a feeling of accomplishment when the screw functions properly.

In order to create a fully functional electric generator, the team recommends that the museum staff consult an electrical engineer to gain a better understanding of the circuitry and its capabilities. The team also recommends testing different materials, such as magnets, wires, and circuit components, to find a combination that produces at least 1.5 volts of direct current.

Appendix A: Sponsor Description

The London Science Museum originally formed from the South Kensington Museum and formally opened in 1928 (“History,” n.d.). Two additional museums, The National Museum of Photography, Film and Television, and the National Railway Museum, opened in England and in conjunction with the Science Museum, form the National Museum of Science and Industry or NMSI (“NMSI,” n.d.). The Science Museum is a large organization that employs 500 permanent employees and 40 volunteers. With two million visitors last year, the London Science Museum is more popular than the Boston Museum of Science, which had approximately one and a half million visitors last year. However, the total number of visitors for last year is lower than most predictions due to the terrorist attacks that occurred in London during the summer of 2005 (“Annual report,” 2006).

The Science Museum is a non-departmental government body run by a Board of Trustees. Because of this, the museum is able to remain a part of the government, but not be restricted in the methods by which the museum receives funds. The museum is an exempt charity and therefore not required to pay taxes (“Annual report,” 2006). As described in “Leisure and Tourism”, the major source of funds for the Science Museum is “grant in aid” and is distributed by the Department for Culture, Media, and Sport (DCMS). The Science Museum is required to work with the DCMS to ensure that the museum uses the grant in aid properly to meet the government’s educational and social priorities (n.d.). While Inland Revenue considers the museum a charity, the museum also receives income through commercial activities, such as fees charged for special museum attractions. These attractions may include the use of simulators or demonstrations, such as live presentations or IMAX showings. Donations, corporate sponsorships, and partnerships also fund the Science Museum (“Leisure and tourism,” n.d.). According to the Science Museum Annual Report and Accounts 2005-2006, last year the Science Museum fundraised £3,521,709 for its priority projects and the “income from third parties was balanced across the trust and foundation, corporate and public sectors creating a more diverse and solid base for project support” (“Annual report,” 2006, p. 9). Overall, the Science Museum uses a solid balance of different sources for funding.

The Science Museum, as part of NMSI, has the vision to “engage people in a dialogue to create meanings from the past, present and future of human ingenuity” (Hewitt, 2002, pg. 5). In an effort to meet this vision, the Science Museum uses its annual operating budget of more than £58 million to offer a variety of learning opportunities, including online resources, for its visitors (“Annual report,” 2006). In the museum, these learning opportunities include an extensive

collection of permanent exhibitions, as well as visiting exhibitions and an Imax® cinema. Each floor includes several galleries, such as Virtual Voyages, Launch Pad, or Marine Engineering. Each gallery is comprised of a set of exhibits related to a particular theme. Over the 2005 fiscal year, the museum set up more than fourteen special exhibits in addition to the permanent exhibits (“Visiting the museum,” n.d.).

Launch Pad is the most popular gallery in the museum with over one million visitors per year (“Science Museum,” n.d.). The gallery is currently being redeveloped to include 55 new or revamped exhibits to accomplish its mission to “inspire [the visitor] to explore and question science and technology through hands-on experience of real phenomena in an environment that promotes curiosity” (“New Launch Pad,” 2006, section 1, para. 3). Once completed, the new Launch Pad gallery will offer a complete learning experience to visitors, specifically those aged eight to fourteen, by encouraging greater depth and duration of learning at each of the exhibits, as well as enhancing the ability of visitors to connect this knowledge to the remaining exhibits in the museum (“New Launch Pad,” 2006).

While the remodeled Launch Pad exhibit will allow museum visitors to learn about a range of scientific phenomena from a set of hands-on and interactive exhibits, the museum would like to further its impact. The Science Museum aims to reach three primary audiences: those preparing for a visit, those who have already visited and would like to reinforce the experience, and those who are unable to visit the museum (“Science Museum,” n.d.). In order to reach these audiences, the London Science Museum operates outreach programs that cover all of the UK and Ireland. These outreach program include traveling shows and a website with online demonstrations, tutorials, quizzes, and games that received nearly seven million visitors last year alone (“Outreach,” n.d.). The Science Museum would like to create extensions that will demonstrate the principles taught in the Launch Pad gallery. These extensions will aid schoolteachers in meeting National Curriculum requirements while inspiring students to explore and question scientific principles (“Science Museum,” n.d.).

Appendix B: Teacher Advisory Panel Schedule

I. Introduction

A. Who we are

1. Hello, my name is Kaitlyn and my group members are Laura, Sean, and Rob
2. We are students from Worcester Polytechnic Institute in the United States completing a study abroad project here at the Science Museum
3. We have been working on this project for the last 3 weeks and will be here until the end of February

B. Why we are here

1. We are developing extensions to scientific principles demonstrated in the Launch Pad exhibition
2. The Science Museum requested that we make prototypes of the Archimedes screw, the electric generator, and the electric motor

C. What we are doing today

1. Today, we are going to present our initial prototypes of the Archimedes screw and the electric generator
2. Through this presentation, we hope to attain very important feedback on our prototypes and their instructions
3. Your feedback and suggestions will lead to the improvements of our prototypes, which will be useful for both the Science Museum's Outreach Box as well as the Online Teacher Resource

II. Archimedes Screw

A. Paper

1. To help us with our development of our instructions, please take some time to construct a model of the Archimedes screw using our instructions and materials
2. Present and handout instructions
3. Handout the materials, including the pre-cut two-liter bottles and seven paper circles for each of you
4. Let the construction begin (approximately fifteen min.)
5. Observe how the teachers handle the instructions and construction of the prototype
6. Ask them to test their prototype with the bucket of peas
7. Show them our smaller prototype
8. Present and demonstrate our larger prototype
9. Ask if anyone has any questions

B. Water

1. Present the prototype
2. Present and handout instructions
3. Explain and demonstrate in water bucket
4. Ask if anyone has any questions

III. Electric Generator

- A. We made two different types of prototypes. At this point, we have constructed what they will look like; however, we have recently received some needed materials and do not have them fully functional yet. Here are the basic ideas
- B. Present and demonstrate Tic-Tac Flashlight
- C. Present and demonstrate Forever Flashlight
- D. Ask if anyone has any questions

IV. At this moment, we are still in the development stage of the electric motor

- V. Here is a feedback form that we would greatly appreciate it if you would take this back with you to your classroom and demonstrate with your students; this would provide us with the necessary information to improve our prototypes
 - A. Provide them with envelopes and address to send back
 - B. Because we will only be here for another month, we would very much appreciate a timely response from you, so we can make the adjustments and make a final design

VI. THANKS

Appendix C: Teacher Advisory Panel Observation Form

Did they read the instructions first?

Did they figure out how to tape the circles together?

Did they tape the circles together before attaching them to the rod?

Did they tape the circles to the rod first?

When the screw is constructed, which way did they turn it?

What were his or her facial expressions? (angry, sad, happy, frustrated, excited, etc.)

Where did the teachers place the plastic bottle? (too far up, too far down, middle, etc.)

Appendix D: Observations from Teacher Advisory Panel

Testing observations

- Teachers need to have a tight spiral of the circles on the dowel
- Teachers tried taping circles to the top of the dowel...confusing instructions
- We had to interrupt teachers if they started to tape the circles on backwards
- After initial troubles, teachers understood what to do
- Teachers confused on how to join the circles
- Teachers tried turning the screw while holding the plastic bottle still
- Need to have a stronger tape
- Teachers relied on pictures for clues for each step
- Teachers tried to begin spiral on wrong end of the dowel
- Teachers worked with each other
- They seemed to enjoy it once they finally started to understand what to do
- Before we handed out the instructions, the teachers were already interacting with the materials
- Two of the eight teachers figured out how to tape the circles together correctly
- Most teachers started taping the circles onto the dowel wrong: they put the spiral on dowel going in the wrong direction
- Teachers looked confused on how to attach circles on the wooden dowel

Instruction suggestions from the teachers

- Frustrating and confusing
- Include letters on picture of materials
- Need a better starting picture on how to connect the tape to the wooden dowel
- Need more pictures
- “Sticky tape”, not “sticky paper”
- Add on to “wrap next circle around dowel and tape to the loose end of the first circle”
- Add on to “slide dowel into bottle and attach crank if desired”
- Need to define exact number of spirals
- Add a scientific description to what the prototype is representing
- Add a description of how it is applied and used in everyday life
- Need clearer instructions on how to start
- Need to define the spacing between the circles on the wooden dowel
- Need to define how to place the circles onto the wooden dowel: coiled up or coiled down
- Need to include in directions something about the circles being tape together to form a spiral

Suggestions for testing with students

- KS2 students may need help cutting out the circles and bottle
- KS3, KS4, and the Gifted and Talented program students should be fine doing all of the cutting
- For electric soldering, students in KS3, KS4, Gifted and Talented, and Science Club can do this
- Appropriate for students making the transition from year 6 to 7

Appendix E: Questions for Teacher Advisory Panel

1. What age group do you think this demonstration is most appropriate for?
2. To what extent do you think that KS2 and KS3 students would fully understand the concepts demonstrated through this activity?
3. What are your thoughts on this demonstration?
4. Is there anything you particularly liked about the demonstration? Can you expand?
5. Is there anything you did not like about the demonstration? Can you expand?
6. How would you improve this demonstration?
7. How do you expect your students to react to this activity?
8. What do you think this activity is about? What do you think this activity is trying to show visitors?
9. How do you think your students will react to this activity? Do you feel that your students will be able to understand the science this activity is trying to show them?
10. How well do you feel this activity links to the National Curriculum?
11. Have you seen or tried anything like this before?
12. How would this activity fit into your teaching?

Appendix F: Answers to Questions from Teacher Advisory Panel

1. What age group do you think this demonstration is most appropriate for?
 - All primary age students
 - All primary students with aid of an adult
 - For KS2 students, the teachers suggested that the students could work in pairs and have the teachers cut out the circles for them.
 - The teacher thought that this demonstration was appropriate for the Science club and the Gifted and Talented club students.
 - Students who are 7 years of age and older with instructions
2. To what extent do you think that KS2 and KS3 students would fully understand the concepts demonstrated through this activity?
 - The teachers thought this activity was for older students: KS2 and KS3 as long as the teacher taught the concepts before completing the demonstration.
3. What are your thoughts on this demonstration?
 - Overall, the teachers thought it was a good activity.
 - The teachers liked both the tube and paper Archimedes screw demonstrations, so they said that when they presented this demonstration to their class, they could start by presenting the paper screw and afterwards present the tube screw.
4. Is there anything you particularly liked about the demonstration? Can you expand?
 - This activity seems like a lot of trial and error.
 - The teachers liked how they can actually make their own screw.
 - The teachers liked the fact that this demonstration dealt with trial and error aspect and made it almost seem like a game.
 - The teachers liked the pre-prepared resources.
 - The teachers wished that they had more time to construct the screw.
5. Is there anything you did not like about the demonstration? Can you expand?
 - The teachers were confused about the wording of “sticky paper.”
 - The teachers suggested that the team change dowel on the materials list to “broom handle” or something along those lines.
 - The teachers thought that the instructions needed more pictures and if online, a video to show what the product should look like.
6. How would you improve this demonstration?
 - The teachers suggested including a “broom” handle under the material list on the instructions, instead of wooden dowel because dowels are expensive.
 - The teachers thought that a video of what the demonstration should look like would be helpful.
 - The teachers suggested that for each step on the instructions the team include a picture.

Appendix G: Classroom Feedback Form

1. Which type of the Archimedes screw did you use? Paper_____ Tubing_____
2. Who constructed the Archimedes screw? Student_____ Teacher_____
3. If the students constructed the screw, what is the first thing that they did (read instructions, look at materials, start constructing, etc.)?
4. On average, how long did it take to complete the construction?
5. How did the materials you used differ from those listed in the instructions?
6. How were you able to incorporate the principle demonstrated by the Archimedes screw into your lesson plans?
7. What do you notice about your students' reactions during the activity?
8. In this activity, what was particularly easy or difficult for your students?
9. How could this activity be improved?

Additional comments:

We would like to thank you for taking the time to participate in our activity and fill out this form. With this feedback, we will be able to make the proper adjustments to ensure a successful extension. Please return to wpi@nmsi.ac.uk or WPI Team, Science Museum, Exhibition Rd., London, SW7 2DD.

Appendix H: Received Feedback Form

Feedback Form from Teachers in Classroom

1. Which type of the Archimedes screw did you use? Paper_____yes
2. Who constructed the Archimedes screw? Student___yes
3. If the students constructed the screw, what is the first thing that they did (read instructions, look at materials, start constructing, etc.)? **Some just started,most read the instructions**
4. On average, how long did it take to complete the construction?
15 mins roughly
5. How did the materials you used differ from those listed in the instructions?
Used the same materials
6. How were you able to incorporate the principle demonstrated by the Archimedes screw into your lesson plans?
yes
7. What do you notice about your students' reactions during the activity?
Very amazed. Thought that they could use this for many things
8. In this activity, what was particularly easy or difficult for your students?
Orientation of screw
9. How could this activity be improved?
I think that it works well

Additional comments:

We would like to thank you for taking the time to participate in our activity and fill out this form. With this feedback, we will be able to make the proper adjustments to ensure a successful extension. Please return to wpi@nmsi.ac.uk or WPI Team, Science Museum, Exhibition Rd., London, SW7 2DD.

Appendix I: Pairwise Comparison

The team organized a matrix with rating categories on the left side from top to bottom and the top from left to right. Next, the team compared each category on the left to each category on the top. When the category on the left was more important than the category on the top, the team placed a one in the square in which they intersected. When the categories were of equal importance, the group inserted a one-half in the square. When the category on the left was less important than the category listed on the top, that category received a zero for that square. After all the squares were completed, the team added the numbers up for each row and placed totals at the end of each row. This number, when compared with the sum of all the numbers, gave the weighting percentage for that category. Since all the designs had common guidelines, the team only needed to make one pairwise comparison chart.

	Safety	Cost	Ease of assembly	Length of demonstration	Aesthetics	Educational purpose	Wow factor	Ease of use	Totals	Weight (%)
Safety	1	0	0	0	0	0	0	0	6	21
Cost	0	1	0	0.5	0	0	0	0	1.5	5
Ease of Assembly	0	0	1	0.5	0	0	0	0.5	3	11
Length of Demonstration	0	0.5	0.5	1	0	0	0	0	2	7
Aesthetics	0	0	0	0	1	0	0	0	0	0
Educational Purpose	0.5	0	0	0	0	1	0.5	0	6	21
Wow factor	0.5	0	0	0	0	0	1	0	6	21
Ease of use	0	0	0.5	0	0	0	0	1	3.5	13
									28	100

Appendix J: Ranking System

Below is an objective system in which to rank each design. For example, when ranking the cost of a design on a scale from one to ten, a one described a design costing more than what was reasonable, a five meant a cost that was appropriate, and a ten described a design that cost much less than what was expected. Once each category had a weighted value, the team took each preliminary design and gave it a specific ranking, from one to ten, on how well it fulfilled the specified tasks.

	1	5	10
Safety	Almost certain chance of injury	50% probability of injury	Almost no probability of injury
Cost	More than £20	£10	Less than £5
Ease of ASS.	Instructions are complicated and take 30+ minutes to complete	Instructions need assistance and takes between 10 and 30 minutes	Instructions are simple and take less than 10 minutes
Length of Demo	15+ minutes	5-15 minutes	Less than 5 minutes
Educational Value	No principles experienced	Parts of principle experienced	Full understanding of principles
Presence of the WOW factor	Never excited	Some are excited	Very excited
Ease of Use	Works less than half the time	Works more than half the time, but not always	Works every time

Appendix K: Decision Matrices

The decision matrices list the designs in the first column and the design criteria in the first row. The team used the weights from the pairwise comparison to weigh the numbers from the ranking system. The team summed the numbers in each row and determined that the design with the largest final value was the best design choice available.

Archimedes Screw

	Safety	Cost	Ease of assembly	Length of demonstration	Educational purpose	Wow factor	Ease of use	Total
Weight Percentage	0.21	0.05	0.11	0.07	0.21	0.21	0.13	= 1
Purchased	10	1	10	10	3	5	10	6.93
Tube	10	10	10	10	6	7	10	8.43
Paper	8	8	6	10	8	9	9	8.18

Electric Motor

	Safety	Cost	Ease of assembly	Length of demonstration	Educational purpose	Wow factor	Ease of use	Total
Weight Percentage	0.21	0.05	0.11	0.07	0.21	0.21	0.13	= 1
Premade	10	1	10	10	5	5	10	7.35
AAA	10	10	4	10	8	9	4	7.83
Energizer	10	6	2	10	8	9	5	7.54
Cup	10	8	7	10	9	9	9	8.92

Tube Archimedes Screw

Hey!

Can you make water climb UP a tube?

Here's how...

What You Need

- A. 2 litre bottle
- B. 1.5 meter of plastic tubing
- C. Sticky tape and scissors
- D. Food colouring
- E. Water
- F. Large bowl
- G. Small bowl



What To Do

1. Fill large bowl with water and add food colouring to the water.
2. Place the small bowl next to the large bowl.
3. Fill the bottle half full with water.
4. Tape one end of tubing to the end of the bottle.
5. Wrap tubing around bottle 3 times and tape the tubing so that there is extra at the top.
6. Place the bottle and tube in the large bowl. Turn until water flows into the small bucket.



Investigation Questions

1. At which angle should you hold the screw?
2. Which direction should you turn the screw?
3. How fast should you turn the screw?
4. Can you build a longer screw?

Notes for Tube Archimedes Screw

WARNING:

Food colouring may stain. If the screw is spun too quickly, water may splatter.

Scientific Principles

- Incline plane
- Simple machine
- Mechanical advantage

The Archimedes screw is simply an incline plane wrapped around a center post. It was first developed by Archimedes in the third century BC and was primarily used for transporting water for irrigation. It is still used today in many applications, such as grain transport.

Materials

It is possible to substitute any of the materials listed for those you have available. A few ideas are:

- 2 litre bottle: Any size plastic bottle
Wooden dowel
Broom handle
- Tubing: Various diameters
Various lengths

Expansion Ideas

- Make a longer screw to move water even farther!
- Create a challenge for the students. For example, have students or teams race to fill equally sized buckets or take the extra tubing and put it inside the bottle. Who can fill the bottle the fastest?

Paper Archimedes Screw

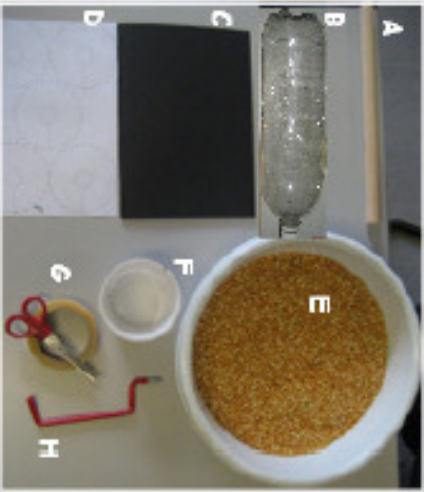
Hey!

Can you make split peas climb UP an inclined spiral???

Here's how...

What You Need

- A. Wooden dowel--35 cm long, 2.3 cm diameter
- B. 2 litre smooth bottle
- C. Card
- D. Template
- E. Split peas
- F. Two bowls (one large, one small)



What To Do

1. Cut the top and bottom off the bottle.
2. Trace the template on card and cut out seven circles.
3. Tape the left tab of one circle to the right tab of another circle. (overlap the white shaded areas)
4. When stretched, the taped circles should resemble a spiral.
5. Repeat until all seven of the circles are taped together.



- Note: The small centre circles must line up precisely.

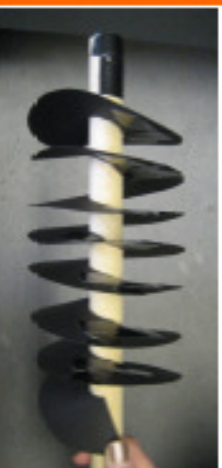


Paper Archimedes Screw Continued

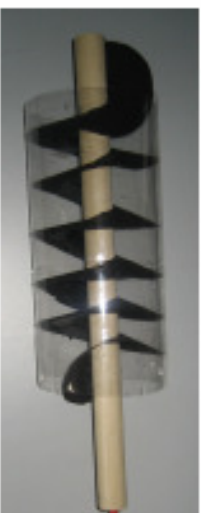
6. Slide dowel through the centre circles of the spiral. Lift up the loose tab of the spiral and tape it towards the end of the dowel. This will be the bottom of the screw.



7. Gently extend the spiral along the dowel and tape the loose end. This will be the top of the screw.



8. Slide the bottle over the screw, starting from the bottom. Stop sliding when the top of the screw is just past the top of the bottle.



9. Place one end of the screw in the large bowl full of split peas. Turn until the split peas fall into small bowl.



Investigation Questions

1. At which angle should you hold the screw?
2. Which direction should you turn the screw?
3. How fast should you turn the screw?
4. Should the bottle turn with the screw?
5. What material moves up the screw fastest?
6. Can you build a longer screw?
7. What jobs could this screw do?

Notes for Paper Archimedes Screw

Scientific Principles

- Incline plane
- Simple machine
- Mechanical advantage

The Archimedes screw is simply an incline plane wrapped around a center post. It was first developed by Archimedes in the third century BC and was primarily used for transporting water for irrigation. It is still used today in many applications, such as grain transport.

Expansion Ideas

- Make a longer screw to move peas farther!
- Create a challenge for the students. For example, have students or teams race to fill equally sized buckets.



Materials

It is possible to substitute any of the materials listed for those you have available. A few ideas are:

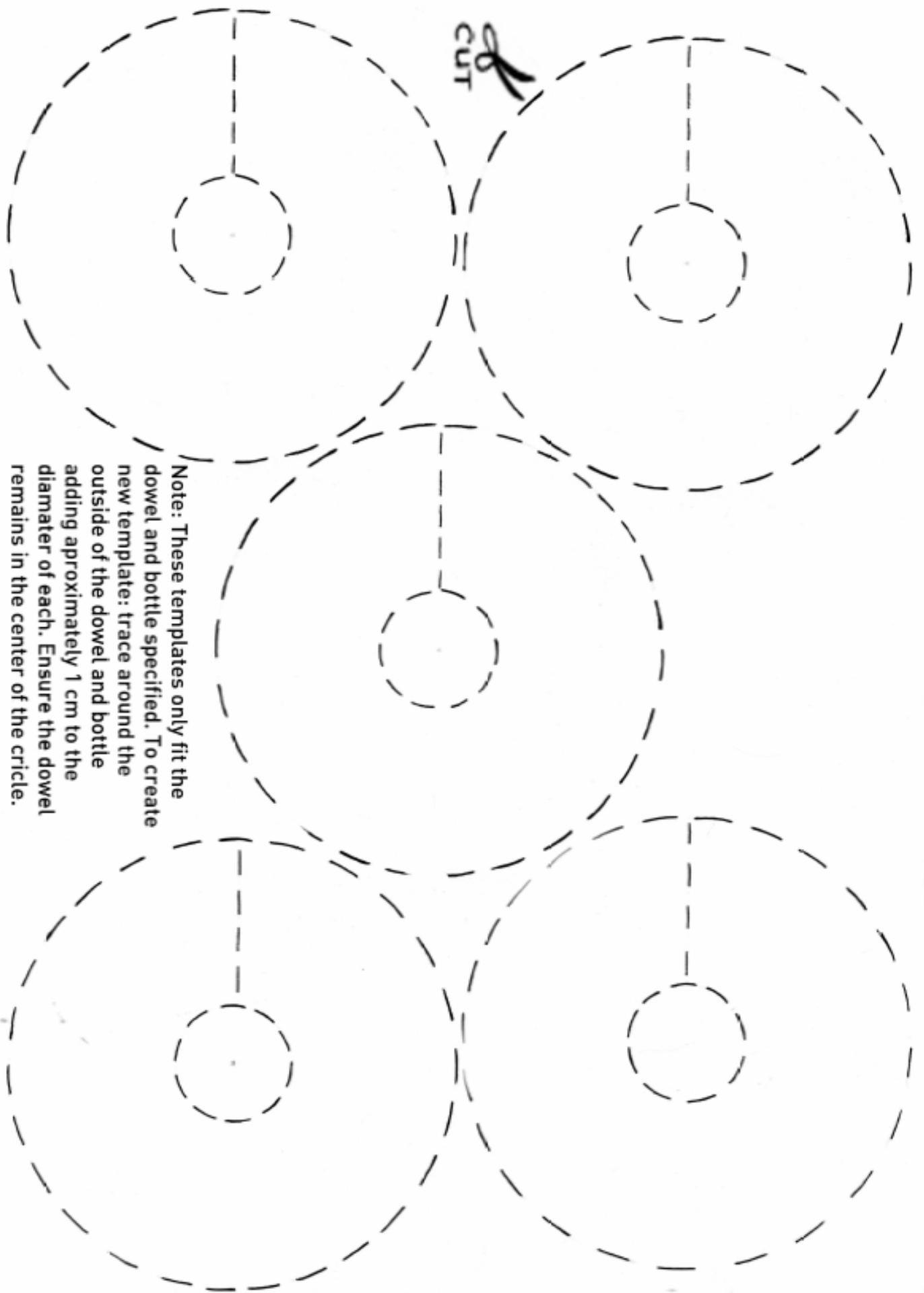
- | | |
|------------------------|---|
| Wooden dowel: | Broom handle* |
| 2 litre bottle: | Any size plastic enclosure* |
| Card: | Light cardboard |
| | Cereal box |
| Template: | To make changes, use the instructions written on the template |
| Split peas: | Rice |
| | Lentils |
| | Plastic beads |

*Note: If you change the diameter of the wooden

Construction Process

10. If desired, drill a hole into the top of the dowel and twist in a crank handle. This provides easier turning, but is not necessary.





Note: These templates only fit the dowel and bottle specified. To create new template: trace around the outside of the dowel and bottle adding approximately 1 cm to the diameter of each. Ensure the dowel remains in the center of the circle.

Electric Motor

Can you make a motor using wire, electricity, and magnets? Here's how...

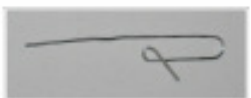
What You Need

- A. 2 AA batteries
- B. 90 cm of 30 standard wire gauge (swg) enamelled copper wire
- C. 2 strong magnets (rare earth shown)
- D. Plastic cup
- E. Tape
- F. Two large paper clips
- G. Sandpaper
- H. Bottle cap
- I. Battery holder
- J. Scissors
- K. Wires with crocodile clips
- L. Ruler (not shown)
- M. Permanent marker (not shown)



What To Do

1. Unfold the outer band of one paper clip.



2. Fold inner bend over itself to create the loop shown.



4. Place one magnet inside the cup and place the second magnet on the other side of the bottom of the cup.



Repeat steps 1 and 2 for the second paperclip.

5. Tightly coil the wire around the bottle cap 8 times, leaving approximately 3.5 cm of wire on each side of the coil.



3. Tape paper clips to each side of cup so that they are standing straight up with their loops above the cup.
Hint: The bottom of each loop must be 12 cm from the table and aligned with each other.



6. Remove the wire from the bottle cap.



Electric Motor Continued

7. Wrap wire tails around the coil in order to keep it together. Leave 2.5 cm tails on each side of the wire coil.



8. Colour wire tails with permanent marker.
9. Fold sand paper around one wire tail. Squeeze the sandpaper tightly and pull wire out (shown in 9a).



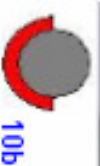
- Continue step 9 until all of the marker and enamel are removed (shown in 9b).



10. Place second wire tail on a sturdy surface. Place sandpaper firmly on top and pull the tail out (shown in 10a).



- Continue until all of the marker and enamel are removed from one side of the tail (shown in 10b).



9. Place the wire coil between the paper clips, letting the wire tails rest in the loops of the paper-clips.



10. Place the batteries in the holder and attach the crocodile clips.



11. Attach the remaining ends of the crocodile clips to the ends of the paperclips.



Investigation Questions

1. Does it matter which way you spin the coil?
2. What happens if you use more or less batteries?
3. What happens if you make the coil larger?
4. Why do you need to strip the enamel from the wires?
5. Does the motor work better with more or less magnets?
6. What happens if you move the coil farther from the magnets?
7. What could an electric motor be used for?

Notes for Electric Motor

WARNING:

1. Wires, paperclips, and coil may get extremely HOT when connected to the battery. Disconnect battery and let the motor cool before making any adjustments.
2. Small sparks may appear where the wire coil and paper clips connect.
3. The magnets are very strong and may pinch the skin if students are not careful with them.

Scientific Principles

- Converts electrical energy into mechanical energy
- Electromagnetism
- There is a mechanical force on any current-carrying wire contained within a magnetic field
- Found in many household appliances such as fans, refrigerators, and washing machines

Expansion Ideas

Cut out two of the pictures provided or two that you drew yourself in the empty circles. Tape each picture to different sides of the wire coil, ensuring that the pictures can be seen. Turn on the motor and see one picture form.

Hint: It is best to use one object, such as a soccer ball, and one frame, such as a soccer net.

Materials

It is possible to substitute some of the materials listed for those you have available. A few ideas are:

Batteries*:

At least 1.5 volt batteries
Voltage supplier

Copper wire*:

Must be enamelled, but the gauge can change slightly

Magnets*:

Varying shapes and strengths

Plastic cup:

Paper or styrofoam cup

Paperclips:

Regular size paperclips, but they offer less support

support

Sandpaper:

Scissors

Bottle cap:

Wooden dowel
Broom handle

Large, round battery

Crocodile clips:

Conductive copper wire with electrical tape for connection

*Note: Batteries with less voltage require stronger magnets and/or higher gauge wire and vice versa.

Appendix O: Tube Archimedes Screw Observation Forms

Water Archimedes Screw: Prototype 1

Hello, my name is...and I work for the Science Museum. We are testing a brand new set of hands-on activities for use in the classroom, which we are developing as exhibit extensions for a new version of Launch Pad that will open next year.

Would any of your class/family be able to help with this testing?

It would only take about ten minutes.

We will be in the Things gallery, just over there.

Thank you.

SAY: I am now going to ask you some questions about the activity. Please be honest. I won't be offended by anything you say. Your answers will help make this activity better.

1. What do you think of this activity?

2. What do you think the activity was trying to teach?

3. How was the water being moved out of the bucket?

4. Was there anything you found difficult or confusing about this activity?

5. What, in particular, did you like about this activity?

6. What, in particular, did you dislike about this activity?

7. What would your friends say about this activity?

8. What can we do to make this activity better for you?

9. Is there anything else you would like to tell us?

10. Do you mind if I ask your age? Your school year?

Age:

Gender:

End time:

Appendix P: Notes from Tube Archimedes Screw Testing in Things Gallery

Testing observations

- Did not read instructions first
- Wound the tube correctly
- Finished in 2 minutes
- Seemed bored and uninterested when screw was constructed
- Did not turn screw in correct direction at first. They needed guidance
- Youngest user (age 7) did not want to test the screw when finished constructing
- Oldest user (age 13) was more interested when Rob suggested a challenge of using the screw to fill up a bucket with the colored water
- None of the users understood what the activity was trying to teach, or the scientific principles behind it
- When asked what his friends would say about the activity, a user responded, “They could be bothered.”

Instruction suggestions

- Make the water go faster
- Make it more clear that both ends of the tubing need to be taped down, not just one

Suggestions through the team’s observations

- Need to rearrange the order of the steps written on instructions
- Need to make it clear that the second end of the tubing also needs to be taped
- Need to add a challenge into the instructions for the activity to be fun for children
- Need to extend length of tubing so the user can see the water travel a greater distance

Discussion

- The tube Archimedes screw is best for students in KS2
- Since the construction only take a minute or two, the teacher should complete the construction and present it to the students
- The students would understand the scientific principle if it was incorporated into lesson plans or if there was a section in the instructions explaining it

Appendix Q: Paper Archimedes Screw Observation Forms

Paper Archimedes Screw: Prototype 1

Hello, my name is...and I work for the Science Museum. We are testing a brand new set of hands-on activities for use in the classroom, which we are developing as exhibit extensions for a new version of Launch Pad that will open next year.

Would any of your class/family be able to help with this testing?

It would only take about ten minutes.
We will be in the Things gallery, just over there.

Thank you.

9. Is there anything else you would like to tell us?

10. Do you mind if I ask your age? Your school year?

Age:

Gender:

End time:

Appendix R: Notes from Science Museum Staff Testing of Paper Archimedes Screw

Testing observations

- Unsure at first about taping the circles together initially; seemed to grasp it soon after
- Checked to make sure the center circle was aligned periodically while constructing screw
- Made sure that the spiral was tight and circles evenly spaced
- Placed bottle on dowel in the correct direction; slid the bottle too far over the dowel
- Unsure of which way to turn the screw

Discussion

- When asked about if the students would like it, declared, “Oh, they’d love that!”
- KS2 students would be able to construct it.
- KS1 teachers could demonstrate screw to students, and then the students could attempt to use the screw.
- The students would like it because they are actually doing something; the students can see it themselves.
- The younger students could go around and try to pick some materials up with their own screw.
- There were no problems with instructions.
- The investigation questions were very good.

Appendix S: Notes from Testing Paper Archimedes Screw in Things Gallery

Testing observations

- User: 13 year old male
 - Read instructions
 - Needed a little help to get to Step 3 of instructions
 - Used pre-cut circles
 - Continued taping on his own once he got the first circle taped
 - Tried to tape the circles to dowel before sliding them on
 - Spiral taped too tight to dowel
 - Concerned about spacing the circles correctly
 - Placed the plastic bottle onto the dowel correctly
 - Laid bottle all the way down and tested the prototype in split peas
 - Bottle slid up
 - Facial expressions include: serious, no smile, concentrated, and excited when it worked
 - Took 16 minutes to complete screw
- User: 11 year old male
 - Needed a little help to get to Step 3 of instructions
 - Used pre-cut circles
 - Did not line up the middle circles
 - Had trouble holding circles and taping
 - Looked at first circles to know how to tape the next one
 - Checked for spiral shape
 - Taped circles tight around dowel, but circles not lined up
 - Spread out circles before taping them to the end of dowel
 - Once the team told him to scrunch the circles, he knew to fold them up and tape them.
 - Circles came apart on dowel; need more tape
 - Had trouble spreading the circles; tried to pull them from the end
 - Knew how to force second end of spiral; did not have any problems
 - Did not spread circles far enough apart
 - Put the bottle on from the top
 - Tested with the screw standing straight up but then put it at an angle in split peas
 - Rotated the screw correctly
 - Facial expressions include: tentative while making it and smiled when it worked
 - Took 15 minutes to complete screw
- User: 9 year old male
 - Read instructions
 - Dangerous with scissors when cutting the plastic bottle
 - Stuck on reading Step 3 in instructions; did not understand the word “tab”
 - Needed left-hand scissors
 - Taped the spiral in right spots on dowel
 - Had a problem keeping the circles aligned
 - Tested with screw standing straight up in split peas
 - The circles seem to have shrunk when she tested it; the circles stretched out and created gaps between spiral and bottle
 - Rotated the screw correctly

- User: 8 year old female
 - Read first step of instructions
 - Watched one of the other testers to understand how to cut the bottle
 - Used pre-cut circles
 - Asked for help; father helped her
 - Did not always read the instructions
 - Tested with the screw standing straight up and down in split peas

Appendix T: Electric Motor Observation Forms

Electric Motor: Prototype 1

Hello, my name is...and I work for the Science Museum. We are testing a brand new set of hands-on activities for use in the classroom, which we are developing as exhibit extensions for a new version of Launch Pad that will open next year.

Would any of your class/family be able to help with this testing?

It would only take about ten minutes.
We will be in the Things gallery, just over there.

Thank you.

SAY: I am going to ask you some questions now about the activity. Please be honest. I won't be offended by anything you say. Your answers will help make this activity better.

1. What do you think of this activity?

2. What do you think the activity was trying to teach?

3. What was making the copper circle spin around?

4. Was there anything you found difficult or confusing about this activity?

5. What, in particular, did you like about this activity?

6. What, in particular, did you dislike about this activity?

7. What would your friends say about this activity?

8. What can we do to make this activity better for you?

9. Is there anything else you would like to tell us?

10. Do you mind if I ask your age? Your school year?

Age:

Gender:

End time:

Appendix U: Notes from Science Museum Staff Testing of Electric Motor

Testing observations

- Worked in pairs
- Started creating the motor without actually reading the instructions; just looked at pictures
- Measured down from the top of the bottle: no specific distance
- Cut more off of the top section because realized it was too high
- Stripped both “ends” of the wire
- Cut the piece of wire too short
- Wrapped wire around 8 times and then cut from the roll
- Read through instructions step by step
- Measured precisely with a ruler and marked the measurement with a pen
- Had difficulty cutting the bottle
- Confused on “.9mm;” they thought it was the length of wire, not the diameter
- When cut the coil, did not leave enough room for the “end” that goes through the paperclips
- Did not strip enough of the wire off the “ends”
- Taped paperclips to bottom part of bottle but figured it out eventually
- Paperclips were not level
- Missed step 10; confused on which wire was noted in step 11
- Confused on how to get the “ends” on both sides of coil of wire
- Constructed motor well but confused on how to troubleshoot
- Did not strip entire length of “end,” so the wire did not contact the paperclip

Instruction suggestions

- Use the actual numbers: 8, not eight
- Use the word “end,” not “tails” in step 5
- Align the pictures with the steps; constructions were confusing sometimes
- Include a step mentioning that when look through the sides of the paperclips, the paperclips need to be level
- Include a specific distance that the loops should be from the ground; this would help to keep them level
- Include “recycle” bottom piece of bottle.
- Include pictures for every step
 - Include picture of coil with a ruler to show measurement
 - Include picture of stripping wire
- Use the word “plastic bottle,” not “soda bottle”

Suggestions through the team’s observations

- Need to say “top half wire,” not top of wire
- Need to say that there needs to be equal lengths of wire on each end of the coil

- Need to mention how the testers can troubleshoot the motor in case that it does not work right away
- Need to say that the tails need to be flat and evenly balanced
- Need more voltage to power the motor
- The suggested 8 loops of coil was too much
- Need to clear up steps 9 and 10: confusing order
- Need to add a ruler or meter stick to the picture of the materials

Discussion

- The electric motor is best for KS3, year 6.
- The KS2 students might struggle with stripping the wire, so the teachers should prepare that first.
- The students would understand the scientific principle as long as they learned about it before actually constructing the motor.
- I was confused about stripping the wire step. Maybe, there should be a cross-sectioned picture of what the wire should look like.
- Maybe, if you link the batteries in series, it could produce more voltage.
- The motor works, but it needs to overcome too many small mistakes or miscalculations.
- The product needs fine-tuning.
- In the instructions, they thought that the “tails” were paperclips and not the end of the wire.
- It would be very difficult to cut the bottle level.

Appendix V: Notes from Science Museum Things Gallery Testing on Electric Motor

Testing Observations:

- Male 12 year old
 - Trouble bending paper clips
 - Didn't align loops of paperclips at first, but fixed it
 - Couldn't get magnets apart
 - Clipped magnets on side of cup and slid up to correct position
 - Measured tail properly before coiling
 - Didn't coil tightly enough
 - Wrapped tails around paperclip instead of coil
 - Paper clips not aligned over magnet
- Male 12 year old
 - Trouble bending paper clips
 - Looked at another student for ideas on how to bend paperclip
 - Wrapped wire tails all the way around the coil so no tails were left
 - Couldn't get magnets apart
 - Was unsure of how to strip wire
 - Twisted the tails around the paperclip instead of resting it on the paperclips
 - Didn't strip enough of the wire
 - Didn't know which side was half stripped when going back to strip more
 - Looked confused the whole time
- Male 12 year old
 - Trouble bending paperclips
 - Wrapped wire around the cup instead of the bottle cap
 - Measured tails before coiling
 - Tried to tape the wire to the cap to attempt to coil wire
 - Eventually just used his hands
 - Didn't coil tightly enough
 - Couldn't get magnets apart
 - Adjusted paperclips and balancing
 - Tried pushing coil to get it going
 - Looked very concentrated

Answers to Electric Motor Questions

1. What do you think of this activity?
 - It was good, but the stripping was complicated
 - It's enjoyable if you get it right
 - It's quite good
 - It was quite fun to do
2. What do you think the activity was trying to teach?
 - How to make an electric motor
 - It's an electric motor
 - Unsure if they learned it in school
3. What was making the copper circle spin around?

- Magnetic field/force
4. Was there anything you found difficult or confusing about this activity?
 - No
 - The pictures help, it is a very good idea
 5. What, in particular, did you like about this activity?
 - I like when it worked
 - I like when you completed it and found out it worked
 - I liked the magnets
 6. What, in particular, did you dislike about this activity?
 - Nothing
 - The sand paper because it was complicated and the stripping was irritating
 7. What would your friends say about this activity?
 - I think they would be interested in it
 - Because I think they'd enjoy playing with the magnets
 8. What can we do to make this activity better for you?
 - Making stripping mote simple
 9. Is there anything else you would like to tell us?
 - No
 10. Do you mind if I ask your age? Your school year?
 - All of them aged 12, year 8

Appendix W: Extension Cost Analysis

This table includes the price of each of the materials needed to construct each extension. However, if a person bought some of these materials, he or she could use the same materials for more than one extension. The team found these prices at local stores in the UK. The cost analysis includes prices of the materials in pounds sterling and dollars.

Prototype Name	Material	Cost per unit (£)	Cost per unit (\$)	Quantity	Total of materials	Total of materials	Distributor
					£	\$	
<u>Paper Archimedes screw</u>	Dowel (2.3 cm. diam., 2 m long)	£8.43	\$16.50	0.175	£1.48	\$2.89	Hornbase
	Handle	£1.50	\$2.94	1	£1.50	\$2.94	Hornbase
	Card	£0.03	\$0.05	1	£0.03	\$0.05	
	Plastic bottle (2 litre)	£0.50	\$0.98	1	£0.50	\$0.98	
	4.5m black PVC tape	£0.69	\$1.35	1	£0.69	\$1.35	Maplin
				Total (£)	£4.19		
				Total (\$)	\$8.20		
<u>Tube Archimedes screw</u>	Plastic tubing (1 m)	£1.49	\$2.92	1	£1.49	\$2.92	Hornbase
	Plastic bottle (2 litre)	£0.50	\$0.98	1	£0.50	\$0.98	Staples
	4.5m black PVC tape	£0.69	\$1.35	1	£0.69	\$1.35	Maplin
					Total (£)	£2.68	
				Total (\$)	\$5.25		
<u>Electric Motor</u>	Plastic cup	£0.0142	\$0.0278	1	£0.01	\$0.03	
	Enamelled copper wire (315mm30swg)	£5.89	\$11.53	0.002	£0.01	\$0.02	Maplin
	Paper clips (31mm)	£0.00189	\$0.00370	2	£0.00378	\$0.01	Ryman
	Alligator clip with lead	£0.40	\$0.78	2	£0.80	\$1.57	RS
	Battery (AA)	£0.37	\$0.72	1	£0.37	\$0.72	Maplin
	Neodymium magnet (10x5mm)	£1.21	\$2.37	1	£1.21	\$2.37	
	4.5m black PVC tape	£0.69	\$1.35	1	£0.69	\$1.35	Maplin
				Total (£)	£3.10		
				Total (\$)	\$6.07		
Note: In regards to the enamelled copper wire, each person will use about 0.5 m of the 250 m of wire on the spool.							
For this reason, the shown quantity is very small.							

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